UNCLE SAM'S DAMPEST CORNER.

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SYNOPSIS.—It is only in recent years that the extraordinarily heavy rainfalls in portions of the Hawaiian Islands have become a matter of record. In the course of their high-level hydrometric work the engineers of the United States Geological Survey found it necessary to measure the rainfall at a number of points at various elevations up to more than 5,000 feet above sea level.

Cherrapunji, with its annual average rainfall of 426 inches, has been generally cited as the wettest place in the world. In a recent period covering nearly 5 years, Mount Waialeale, elevation 5,080 feet, on the Island of Kauai, Hawaiian Islands, averaged 476 inches of rainfall annually. In this period of 1,782 consecutive days the total precipitation was 2,325 inches—a daily average of 1.30 inches.

Another very striking feature of the rainfall records in the Hawaiian Islands is the great contrast in amounts in stations separated by only a few miles but with considerable differences in altitude or exposure. Six photographic illustrations give an excellent idea of the topography of the country while the two remaining figures show the realtive sizes of the special rain gages employed, and the mean monthly rainfall variations.—H. L.

Cherrapunji, in the Khasi Hills in India, which is said to have the greatest known annual rainfall on the earth, has a rival for the world's maximum wetness in Mount Waialeale, elevation 5,080 feet, on the Island of Kauai, Hawaiian Territory.

According to the Memoirs of the Indian Meterological Department, volume 22, 1913, the mean annual rainfall at Cherrapunji is 426 inches. The maximum precipitation is supposed to have occurred in 1861, when 905 inches was recorded, but there are grave doubts concerning the accuracy of this record.

During the periods August 2, 1911, to March 26, 1914, and May 31, 1915, to August 13, 1917, a total of 1,782 days, there was recorded on Mount Waialeale a total precipitation of 2,325 inches, or an average of 1.3047 inches per day. In a 365-day year this would amount to an annual precipitation of about 476 inches. The years of 1918 and 1914, for which, unfortunately, no records were obtained, were the wettest since the local Weather Bureau office was established in the Hawaiian Islands. Though comparative estimates are always unsatisfactory, reliable records obtained at near-by stations indicate that in both 1914 and 1918 the rainfall at this station exceeded 600 inches. From May 21, 1915, to May 30, 1916, the recorded rainfall at Mount Waialeale was 561 inches.

Mount Waialeale (figs. 1 and 2) is the peak of the island of Kauai, and is inaccessible except to the most expert mountaineers. For this reason it has been very difficult to maintain the station and it was finally discontinued on account of inability to get mountaineers to make the necessary regular visits.

There are several other damp spots in Hawaii. Puu Kukui, 5,000 feet above sea level, on the island of Maui, has for the last 7 years had an average precipitation of 369 inches, the maximum being 562 inches in 1918. On the island of Hawaii, at the intake of the Upper Hamakua irrigation ditch, 4,000 feet above sea level, rainfall amounting to 504 inches was recorded in 1914. At at least a dozen other spots—all more than 1,000 feet in elevation—in the Territory the rainfall in 1914 and 1918 exceeded 350 inches. The heaviest daily downpour ever recorded in the Territory was 31.95 inches at Honomu, Hawaii (elevation 1,200 feet), February 20, 1918.[1] According to the Weather Bureau record the total rainfall at this station for the year was 379 inches.

Except those collected at Honomu, practically all the high-level records have been obtained by engineers of the water-resources branch of the United States Geological Survey, or by parties cooperating therewith, for the local office of the Weather Bureau has been unable to collect daily records except those furnished free of cost by cooperative observers who could obtain the records at a minimum expenditure of effort. As a result nearly all the records published by the Weather Bureau are for low elevations, and as the higher levels of the Hawaiian mountains are practically uninhabited it has devolved on the Geological Survey to establish the high-level stations needed to obtain data to be used in connection with its hydrometric work. The records most needed are those for places on the upper ridges and peaks and in the upper reaches of valleys where only wild cattle and pig trails—or no trails at all—existed (fig. 3), and where no human being could possibly have set foot previous to the construction of trails by the Geological Survey.

The Hawaiian group comprises eight islands worthy of name, of which five, Kauai, Oahu, Molokai, Maui, and Hawaii have populations exceeding 1,000. The areas of these islands, in the order above named, are, 547, 598, 261, 728, and 4,015 square miles. All are characterized topographically by high central mountain ridges or peaks with many narrow precipitous valleys (figs. 4–6), as a rule flattening out to narrow plains along the seacoast. The lower slopes, saddles, and coastal plains up to levels of about 2,000 feet are usually the inhabited agricultural lands; the upper reaches are usually included in forest reserves set aside primarily to conserve and regulate stream flow. Few valleys are more than 10 or 12 miles long from ridge to costal plain, and in this distance they drop from elevations of several thousand feet to near sea level.

Except where irrigation ditches divert the valley drainage or electric-power lines cross the ridges, or where a few cattle ranches or mountain houses stand, there are few trails other than those made by wild cattle and hogs; and as a rule these trails are not adapted for human use in respect to location, overhead clearance, or foundations. In these upper valleys, also, where the rainfall is excessive and the forest cover almost of the jungle type, the soil is usually saturated and the going is very heavy. Accordingly reconnaissance work is rather strenuous, and where regular visits must be made foot trails from 3 to 8 miles long usually have to be constructed.

Of course, under these conditions, it is practically impossible to obtain daily rainfall records, and accordingly three types of raingages and an evaporation gage to measure the evaporation from the raingages (if any), to be read at monthly or longer regular periods, have been designed. The gages first installed were made of galvanized iron, but as experience proved that these would rust out in two or three years, those recently installed have been of copper.

The three types of raingages have capacities of 48, 150, and 300 inches, and the ratios of receivers to containers are 1 to 2, 1 to 5, and 1 to 10, respectively. (See fig. 7). All raingage receivers are of the standard type adopted by the United States Weather Bureau, and the top of the evaporation gage is an exact duplicate of the raingage receiver, except that the interior cone is inverted and a small cap about 2 inches in diameter is superimposed over the hole in such a way that it will keep out rain but will not prevent the effect of wind. Where it has been

[1] Cf. Table 2, p. 302.

demonstrated that there is appreciable evaporation, the raingage is never entirely emptied so that the evaporation will be continuous for the entire period between readings.

Rain and evaporation gages are "read" by merely measuring depths in containers with the ordinary reading stick used by the Weather Bureau and the actual depths, in inches, in the containers are then multiplied by the receiver-container ratios and corrections made for evaporation. An effort is made to get as many records as possible at the end of months and years, but as it is impossible with the available assistants to have all gages read on the first or last days of months and years, the readings obtained do not all furnish exact monthly or annual records, but they are usually very close approximations.

Though Hawaii may have to be satisfied with second place as to annual quantities of rainfall, it challenges the world for variation in precipitation with vertical or horizontal distance.

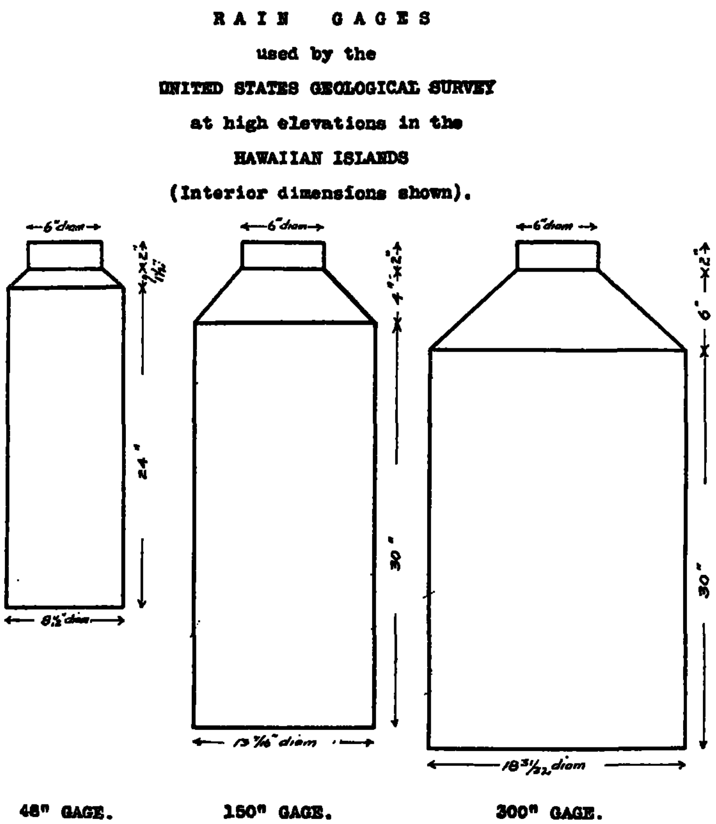

FIG. 7.—Rain gages used by the U. S. Geological Survey at high elevations in the Hawaiian Islands. (Interior dimensions are shown.)

Starting with Mount Waialeale, elevation 5,080 feet, on Kauai, with a mean annual precipitation of 476 inches, we have the following records, covering practically the same period.

	Elevation.	Miles.	Inches.
	Feet.		
Mount Waialeale	5,080	....	476
Olokele	2,100	2.0 sw.	149
Kokee	3,550	10.5 nw.	56
Pali Trail	850	11.0 sw.	16
North Wailua	650	4.0 e.	126

On Oahu likewise are wide variations. Within a radius of about 6 miles from the United States Weather Bureau central station, which is in Honolulu on the roof of the Alexander Young Building, elevation 112 feet, in the heart of the business district, and at which the annual precipitation is 31 inches, are the following stations:

	Elevation.	Miles.	Inches.
	Feet.		
Honolulu	112	....	31
Municipal Electric plant	405	2.5 nw.	82
Upper Luakaha	1,110	5.0 ne.	160
Puu Loa	15	6.0 w.	22

At the intake of the Wahiawa Water Co.'s ditch, elevation 1,200 feet, the mean precipitation is 231 inches; at Wahiawa village, elevation 950 feet, 5.5 miles west, the mean is only 57 inches.

On the island of Maui the variations are still more remarkable. Stations near Puu Kukui, elevation 5,000 feet, with a mean of 369 inches (562 inches for 1918), give the following records:

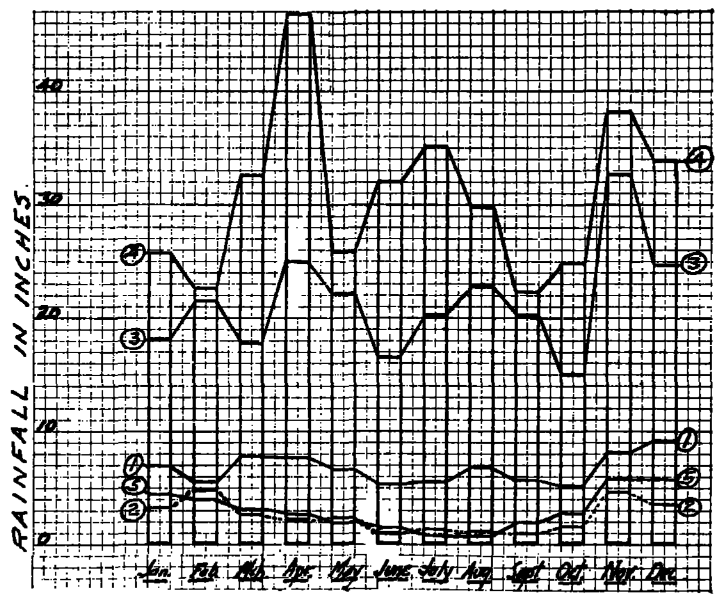

FIG. 8.—Mean monthly rainfall variations in the Hawaiian Islands. Nos. 1, 2, and 5 for 14-year period ending Dec. 31, 1918. Nos. 3 and 4 for 7-year period ending Dec. 31, 1918.

Means for Nos. 1, 2, and 5 for the 7-year period ending Dec. 31, 1918, approximately the same as for the 12-year period.
1 All Weather Bureau stations on all islands.
2 Weather Bureau office station, Honolulu. El. 112 feet.
3 Weather Bureau station, Honomu, Hawaii. El. 1,200 feet.
4 U. S. Geological Survey station, Puu Kukui, Maui. El. 5,000 feet.
5 Weather Bureau station, Seattle, Wash.

	Elevation.	Miles.	Inches.
	Feet.		
Puu Kuki	5,000	....	369
Kahoma Reservoir	2,000	4.0 w.	55
Kaanapali	12	7.5 nw.	18
Wailuku village	390	5.5 se.	30

Disregarding chronology, topography, and geography, Puu Kukui, elevation 5,000 feet, during 1918 had 562 inches; at Camp No. 7 of Pioneer Mill Co., elevation 90 feet, less than 8 miles southwest, 2.47 inches was recorded in 1912.

As a rule November, December, March, and April are the wettest months, although the rule is not "hard and fast," and records are available showing just the reverse. A comparison of local records with those on the mainland northwest indicates no relation whatever in seasonal precipitation. The graphs (fig. 8) show a fairly close relation between rainfall at Seattle and Honolulu, but the graphs for all Weather Bureau stations and for the high-level stations maintained by the United States Geological Survey in Hawaii show no such relation.

Hawaiian precipitation is also of the "showery" class, and heavy rains rarely last more than a few hours. The applicability of the general rule—that even in wet periods heavy downpours lasting a few minutes are interspersed with short periods of sunshine—varies considerably with the altitude and location. In the upper valleys, with few exceptions, showers are daily occurrences, even in dry weather, though on extreme leeward points showers are rare. On the high peaks, like Mount Waialeale and Puu Kukui, the mornings are usually clear and the afternoons and nights *very wet.*

ADDITIONAL METEOROLOGICAL DATA NEEDED BY ENGINEERS.

[Points on which more data or further study would be helpful, including rainfall distribution and intensity, precipitation and heavy floods, evaporation, vegetation, soil infiltration, temperature, run-off.]

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Every experienced hydraulic engineer feels the need of additional meteorological data. First of all, there are far too few rainfall stations, and where the stations are reasonably close together group records should be studied to gain light for use where the stations are far apart. Periodic distribution of precipitation, rainfall intensities, flood flows, evaporation, the influence of vegetation, soil percolation, temperatures of the air and of the surfaces of both soil and water, and, finally, the broad general phases of run-off—all need attention. A brief review of the more important meteorological needs, grouped under 10 heads, follows:

1. *More stations.*—A much larger number of rainfall stations is needed throughout the country generally. In the East there is generally one station in each county, an average of about one station to every 1,500 square miles. In England, Denmark, Saxony, Jamaica, Barbados, St. Kitts, Victoria, and Mauritius there is an average of about one station to every 40 square miles. That is sufficient to provide good data for almost any small drainage basin, such as is commonly required for gravity water-supply systems. In New England the number of rainfall records available is about twice as great as elsewhere in the United States, owing to the fact that many good records are maintained in conjunction with water-works systems. But even in New England the number of stations is by no means adequate for satisfactory determination of the rainfall on many small drainage basins used for gravity water supply.

2. *Special group studies.*—In view of the sparsity of rainfall records, special groups of stations are needed, and studies based on existing data to determine the reliability, both of the long-term mean for any one station and the actual annual and monthly amounts indicated by single gages when applied over a varying radius of 1, 5, 10, or 15 miles from the station. Data are available at Providence, Worcester, Pawtucket, St. Louis, and New Orleans, where raingages are maintained sufficient in number to determine the general accuracy of a single record as applied to larger or smaller surrounding areas in those particular localities. Undoubtedly, with more data general relations could be established which would greatly increase the utility of rainfall records, and would also increase the degree of confidence which could be placed in such records where it becomes necessary to apply a single station to a considerable area.

3. *Periodic distribution of rainfall.*—Experience shows that with identically the same rainfall distributed in different ways throughout the year, especially during the summer, quite different amounts of run-off may result. In applying rainfall data, in critical cases, it is, therefore, necessary to take into account its distribution as well as its total amount. It is desirable, therefore, that the total number of rainfall days per month at each station should be published, with the amount of rainfall. For example: A rainfall of 4 inches in August may all occur in four days, with heavy thunderstorms, or it may be distributed throughout 10 or 20 days. In the latter case, the opportunity for water loss by evaporation would be enormously increased by the long-continued wetting of the ground surface, and the available supply for run-off would be steadier, but much smaller in amount than in the case of concentrated rainfall. I believe that practical methods can be readily developed by which the effect of rainfall distribution can be taken into account in estimating stream yield, if the number of rainfall days is known.

4. *Intensities.*—As regards rain intensity, there are at present about 200 stations in the United States with recording raingages. The details of these records, some of them running back to 1896, are published in the Monthly Weather Review and in the annual reports of the Chief of the United States Weather Bureau. No complete, exhaustive analyses of all these records have ever been made. Partial analyses, covering the records within considerable areas, or for a considerable number of stations, have recently been made by Meyer and published in his "Elements of Hydrology," and by the United States Housing Corporation, the results not yet having been published. So far as the results go, they indicate that rain intensity formulas of the same type, but with varying coefficients, can be applied to localities having widely different amounts of rainfall.

Practice hitherto in using rain-intensity data in storm-sewer designing has been in general to work out a rain-intensity curve for each different place or problem. Usually, the data of the most intense and most critical storms are meager, and the results of such scattered individual studies are unquestionably less reliable than would be those obtained by thorough, general analyses involving a large number of stations of similar rainfall characteristics. There is room for much valuable work in standardizing and analyzing rain-intensity data along more general lines. Not only this, but all attempts hitherto to utilize such data have been wholly empirical. There is reason to believe that at least a semi-rational formula of general application can be developed for rain intensities of short durations.

5. *Great storms and floods.*—In connection with the broader problems of flood causation and flood discharge, studies of rain intensity in great storms covering periods of one to five days are needed. A valuable start was made in this direction by the Miami Conservancy District, the results being given in its series of technical reports, part 5. Good work along similar lines, with much more numerous records on which to base the results, has been done by the British Rainfall Organization.

One of the most fundamental problems of flood control is the determination of the relative frequency of occurrence of floods of different magnitudes, as fixing the